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Epoxies for Cryogenic Applications

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1. Introduction

Superconducting magnet applications often require the use of epoxy adhesive to join dissimilar materials, with very different coefficients of thermal expansion. The bonded assembly is often required to be strong enough to withstand cryogenic temperatures. One such application is bonding together of a magnetic (such as low carbon steel) and a non-magnetic (such as brass) material for making tuning shims [1] for magnetic field optimization. This note describes the results of an investigation performed to find a suitable epoxy for bonding 0.625" wide pieces of brass and low carbon steel together, for use at cryogenic temperatures.

2. Background

Fig. 1 shows a schematic of a single lap joint. The average shear stress for such a joint is given by:

$$t_m = P/bl,$$

where P is the applied load, b is the joint width and l is the joint length. However, note that this is a simplistic equation and does not take into account any shear deformations in the adhesive.

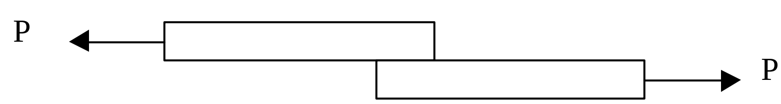

Figure 1: Schematic of a single lap joint.

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A theory was developed by Volkersen by assuming that the adhesive deformed only in shear and that the adherends deformed only in tension. Volkersen developed an equation for the shear stress distribution at any position x along the length of a single-lap joint as:

$$\bar{t} = \frac{w}{2}\frac{\cosh wX}{\sinh w/2} + \left(\frac{y-1}{y+1}\right)\frac{w}{2}\frac{\sinh wX}{\cosh w/2},$$

where $\bar{t} = t_x / t_m$, $w^2 = (1+y)f$, $y = t_1 / t_2$, $f = Gl^2 /(Et_1 t_3)$, $X = x / l$, and $-1/2 \le X \le 1/2$. In addition, G is the shear modulus of the adhesive, E is the Young's modulus of the adherends, l is the length of the bonded region, t_1 and t_2 are adherend thicknesses, and t_3 is the adhesive thickness.

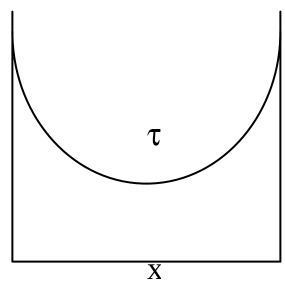

Figure 2: Shear stress distribution for a single lap joint.

Fig. 2 shows a schematic of the shear stress distribution in a loaded single lap joint, when shear deformations in the adhesive are taken account of. It is observed that the shear stress in the adhesive is maximum at each ends and a minimum in between. Note that our particular application required joining together of 0.625" wide pieces of brass and low carbon steel of maximum permitted lengths, such that no debonding would occur at cryogenic temperatures. Since the shear stresses increase with the length of the specimen (as seen it Fig. 2), it was necessary to find an epoxy with a high value of lap shear strength.

3. Results

Several different epoxies were identified based on the values of their lap shear strength and their claim as being cryogenic epoxies (see Appendix). Table 1 provides mechanical properties (provided by the manufacturers) of some of the epoxies which were tested. Samples of brass and low carbon steel, 0.625" wide and 0.080" thick, were bonded together using different epoxies. Several samples were made of different lengths and thermally shocked in liquid nitrogen repeatedly. Table 2 summarizes the result of these tests. It is observed that Hysol EA 9430 and Lord 3170 appear to be the best epoxies for bonding dissimilar materials for cryogenic applications. Both of these epoxies also have very high values of lap shear strength. To check the lap shear strength values provided by the manufacturers, it was decided to do overlap shear tests in the Material Development

Laboratory. Fig. 3 presents the lap shear strength values of different epoxies as tested in-house. It is again observed that both Hysol EA 9430 and Lord 3170 have very high values of lap shear strength, higher than the other epoxies tested. Thus, it is envisioned that these two epoxies would be useful for bonding dissimilar materials subjected to cryogenic temperatures.

Epoxy	Lap Shear Strength (psi)	Peel Strength (lb/inch)	Ultimate Tensile Strength (psi)	Tensile Modulus (psi)	Elongation at Break (%)
828/ V-3140	3625	870 (psi)	8,800		4.0
828/ DPC 3164	1,002	8.8	3,782	213,000	189.0
Hysol EA 9430	4,700 (298 K) 5,000 (218 K)	60	5,300	380,000	6.0
Araldite 2042 (Polyurethane)	1,450		2,100		250.0
Lord 3170	3,000 (298 K) 2,500 (218 K) 2,500 (20 K)	5			
Stycast 2850 FT			8,400		

Table 1: Mechanical properties of various cryogenic epoxies.

Epoxy	Length=5”	Length=12”	Length=18”	Length=24”
828/V-3140	Debonding	—	—	—
828/ DPC 3164	No debonding	Debonding	—	—
Oxford Epoxy	No debonding	Debonding	—	—
Stycast 2850FT	No debonding	Debonding	—	—
Araldite 2042	No debonding	No debonding	Debonding	—
Lord 3170	No debonding	No debonding	No debonding	No debonding
Hysol EA9430	No debonding	No debonding	No debonding	No debonding

Table 2: Results from repeated thermal shocking of bonded brass/low carbon steel in liquid nitrogen.

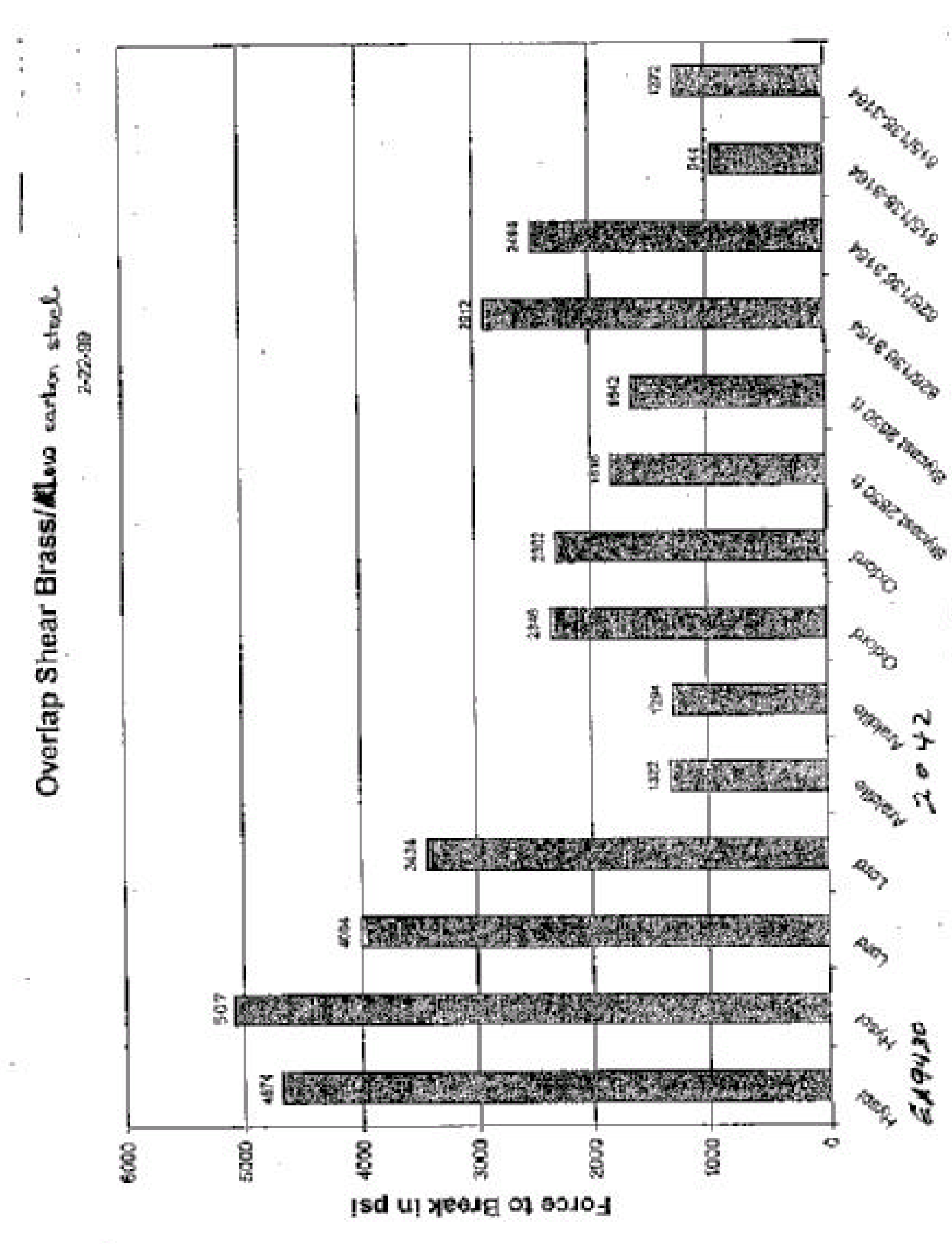
Overlap Shear Brass/1010 carbon steel
2-22-99
Force to Break in psi
6000
5000
4000
3000
2000
1000
0
Hysol
Hysol
Lord
Lord
Araldite
Araldite
Oxford
Oxford
Stycast 2850 ft
Stycast 2850 ft
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FIG. 3

Appendix

Hysol EA9430

EA9430 is a modified epoxy adhesive that attains structural properties after room temperature cure. This two-part adhesive is formulated to give very high peel strength coupled with excellent shear strength. The tough, flexible nature of this adhesive makes it useful for bonding dissimilar substrates. Some of the salient features are:

- High Peel and High Shear Strength
- Excellent Low Temperature Properties
- Bonds Variety of Substrates
- Room Temperature Cure

Araldite 2042

Araldite 2042 is a polyurethane adhesive that produces good bond strength on materials of different coefficients of thermal expansion.

Oxford Resin Adhesive

It is a bonding adhesive which remains flexible enough at helium temperatures to make mechanical joints which remain strong after repeated thermal cycling. It is suitable for bonding materials with dissimilar coefficients of expansion.

Lord 3170

It is a two-component modified epoxy that provides strength to applications where the bonded assembly will be exposed to cryogenic temperatures.

References

[1] R. Gupta, M. Anerella et al., “Tuning shims for high field quality in superconducting magnets,” Fourteenth International Conference on Magnet Technology (MT-14), Finland, 1995.